Characteristics of neighbourhoods with high incidence of out-of-hospital cardiac arrest and low bystander cardiopulmonary resuscitation rates in England

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Aims

The aim of the project was to identify the neighbourhood characteristics of areas in England where out-of-hospital cardiac arrest (OHCA) incidence was high and bystander cardiopulmonary resuscitation (BCPR) was low using registry data.

Methods and results

Analysis was based on 67 219 cardiac arrest events between 1 April 2013 and 31 December 2015. Arrest locations were geocoded to give latitude/longitude. Postcode district was chosen as the proxy for neighbourhood. High-risk neighbourhoods, where OHCA incidence based on residential population was >127.6/100 000, or based on workday population was >130/100 000, and BCPR in bystander witnessed arrest was <60% were observed to have: a greater mean residential population density, a lower workday population density, a lower rural–urban index, a higher proportion of people in routine occupations and lower proportion in managerial occupations, a greater proportion of population from ethnic minorities, a greater proportion of people not born in UK, and greater level of deprivation. High-risk areas were observed in the North-East, Yorkshire, South-East, and Birmingham.

Conclusion

The study identified neighbourhood characteristics of high-risk areas that experience a high incidence of OHCA and low bystander resuscitation rate that could be targeted for programmes of training in cardiopulmonary resuscitation and automated external defibrillator use.

Keywords

Bystander cardiopulmonary resuscitation • Pre-hospital cardiac arrest • Neighbourhood characteristics

Introduction

Data from the Out-of-Hospital Cardiac Arrest (OHCA) Outcomes (OHCAO) project for 2014 indicate that bystander cardiopulmonary resuscitation (BCPR) is undertaken, on average, in only 40% of

OHCA in England, the figure increases to about 55% in non-Emergency Medical Service (EMS) witnessed cases.¹ A low BCPR rate may, in part, explain why survival to hospital discharge (SHD) from OHCA in England is also low, 7.9%,¹ as BCPR, a resuscitation attempt performed by a layperson who is not part of the organized

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Key Messages

- High-risk neighbourhoods, with a high out-of-hospital cardiac arrest incidence and low bystander cardiopulmonary resuscitation rate, were characterized by higher population density and increased urbanization; higher proportion of population in intermediate and routine occupations, lower proportion of people in managerial occupations; greater proportion of mixed race and non-white ethnic background, and lower proportion of white ethnic background; fewer people with higher educational qualifications; and a greater level of deprivation.
- High-risk areas were seen across the country, and included city centres like Birmingham and London, parts of the north-east and Yorkshire; and some were on the coast in the south-east and east Yorkshire.
- Knowing the characteristics and locations of high-risk areas could help focus future cardiopulmonary resuscitation training campaigns to where they are required most and have the biggest impact on improving survival after cardiac arrest.

emergency response system, more than doubles the chances of survival from an OHCA.²

The community in which a person lives and works not only has an important influence on the likelihood that they have an OHCA but also on the probability the event is witnessed and also that they will receive BCPR and ultimately survive.³ Previous research in the USA has shown BCPR incidence was lower in black/Latino/Hispanic neighbourhoods (compared to white neighbourhoods), regions of lower income (greater number living in poverty), areas of low levels of education, and areas with older population.^{3–8} High-risk communities (where the incidence of OHCA is high and the prevalence of BCPR provision is low) are an important potential target for public health interventions to help reduce disparities in BCPR and to ultimately improve OHCA survival. Identification of areas of disparity could help direct strategies to areas be designed and implemented, moving from the notion of a one-size-fits-all approach to BCPR training, to one that is targeted where the need is the greatest.

The aim of this project was to examine the OHCA incidence and BCPR rates of bystander-witnessed OHCA across England, using OHCAO registry data for 2013–2015 to identify neighbourhood characteristics associated with high frequency of OHCA and low uptake of BCPR.

Methods

Analysis was based on OHCA events between 1 April 2013 and 31 December 2015. In the OHCAO registry, OHCA patients of all ages where resuscitation was commenced or continued by EMS personnel are included. Patients who had a 'Do Not Attempt Cardiopulmonary Resuscitation' decision in place, or where a return of spontaneous circulation (ROSC) was achieved before arrival of EMS are excluded. The registry does not include cases that were bystander-witnessed, received BCPR, and achieved ROSC before ambulance arrival. This is because it is difficult to determine if such a case is actually a 'true' OHCA, which would only be possible if an automatic external defibrillator had been attached to the patient and given a shock, an event only observed in a small number of non-EMS witnessed cases.¹ For this reason, when the OHCAO registry was set-up the ambulance services were instructed to not send details of such cases.⁹ A patient was diagnosed dead on EMS arrival according to recognition of life extinct criteria¹⁰ and were not included in the registry.

Age at date of OHCA was calculated from the patient's date of birth. If the calculated age was missing or out of a reasonable range (0–110 years), it was replaced by the EMS estimated age. According to the updated Utstein definition, unknown initial aetiology was recoded as a cardiac

cause (presumed).¹¹ The initial cardiac rhythm was defined into two different classifications. A shockable rhythm included ventricular fibrillation (VF) and pulseless ventricular tachycardia (VT); and a non-shockable rhythm included asystole, pulseless electrical activity, and bradycardia.

The incidence of OHCA was defined in two ways. Firstly, as the total number of OHCA events, over the 33 months, per 100 000 resident population served (residential population incidence); population data were taken as the average mid-year estimates for 2013–2015 published by the UK Office for National Statistics (ONS). Secondly, per 100 000 workday population based on UK 2011 Census returns; with workday population, the usual residential population is re-distributed to their places of work (for those aged 16 years and over), while those not in work are recorded at their usual residence. The BCPR rate was defined as the proportion of bystander-witnessed OHCA receiving CPR by a layperson or bystander.

Geocoding Emergency Medical Service location

Out-of-hospital cardiac arrest location information was geocoded using online software (<https://www.doogal.co.uk>). In cases where the software failed to give a valid postcode, a manual process was undertaken to search for the address using the internet. A random sample of those locations that were automatically geocoded was checked manually. Postcode district (PCD), of which there are 2091 in England, was selected as the proxy unit of neighbourhood to ensure the number of OHCA cases was sufficient to not decrease the power of the analyses to detect any differences. An OHCA was categorized as 'Home' if the postcode from the geocoded EMS location was the same as the postcode of the patient's address (if provided), or if the EMS location was given as 'Home' or 'Place of Residence' and the patient's address was provided that allowed geocoding. If the geocoded EMS location and patient's address did not match, or the former was given as something else, e.g. 'Public Place' or 'Workplace', then the location was categorized as 'Other'. If neither of these criteria were met then the location was categorized as 'Unknown'.

Population data

Neighbourhood characteristics were obtained from the UK 2011 Census (www.nomisweb.co.uk). Information on the proportion of the population in each PCD was obtained for the following:

- Ethnic group: People classified themselves as whites, non-whites, or mixed race;
- Long-term health problem or disability: People indicated they had a long-term physical health condition that limited their day-to-day activities or not at all;

- Highest level of qualification: The highest level of educational qualification achieved of people aged 16 and over, categorized as 'Yes' (levels 2, 3, 4 or apprentice) or 'No' (None, Level 1 or other);
- National statistics socio-economic classification: People that indicated their occupation was (i) higher managerial, administrative and professional (higher); (ii) intermediate; or (iii) routine and manual, never worked, or long-term unemployed (routine).
- Age: Census age categorized as <65-years or ≥65-years.
- Country of birth: Categorized as UK, other EU, or other countries.
- Household deprivation: People with zero, 1, 2, 3, or 4 dimensions of deprivation; dimensions were based on four selected household characteristics (employment, education, health and disability, housing), categorized as 'Yes' (1, 2, 3, or 4 dimensions) or 'No' (zero).

In addition, the average of the following information for each PCD was obtained:

- Resident population density: Population per hectare (ha); continuous and categorized (<1, 1–<10, 10–<50, 50–<100, ≥100);
- Workday population density: An estimate of the population during the working day. It includes everybody who works in an area, wherever they usually live, and all respondents who live in the area but do not work. Continuous and categorized as for resident population density.
- Rural–urban classification: An official statistic used to distinguish rural and urban areas.¹²
- Index of multiple deprivation (IMD): Measures relative levels of deprivation in small areas of neighbourhoods¹³; IMD is a non-linear measure of community socioeconomic status. For the analysis patients were categorized into quintiles of small-area deprivation, where the first quintile indicated the least deprived and the fifth quintile the most deprived group.

One PCD was excluded from the analysis because we could not obtain neighbourhood characteristics for it; this was the PCD for Heathrow Airport.

Choropleth maps

Visual maps were created using ArcGIS 10.3 (Esri Inc.) to illustrate spatial patterns in OHCA incidence and BCPR rate.

Statistical analysis

Descriptive statistics were used to analyse the difference in neighbourhood characteristics (*t*-test). Logistic regression analysis was undertaken to examine which neighbourhood characteristics might influence whether a PCD is defined as high-risk or not. Initially, single variable regression models were developed; any variable with a *P*-value ≤0.2 in the bivariate analysis was integrated into the final model. A backwards stepwise regression model was then developed, using a significance level of *P* > 0.1 for removal from the model. Before running the model, the variables were tested for multi-collinearity using pairwise correlation. Goodness-of-fit of the model was assessed by the Hosmer–Lemeshow test, and area under the curve (AUC) was used to test the model's ability to correctly classify whether a PCD was high-risk or not. All statistical analyses were carried out using Stata version 15 (Statacorp, USA).

Results

This analysis was based on a total of 67 219 (88%) of the eligible 76 456 OHCA cases (Table 1; see [Supplementary material online, Figure S1](#) for Utstein flowchart). Approximately 42% of cases were witnessed by a bystander. The mean age (69.5 years) of these cases

was significantly greater than that of all cases (67.8 years; *P* < 0.0001). Over the 3 years the proportion presenting with a shockable rhythm averaged around 28%, and approximately 80% of cases were of cardiac aetiology. About 65% of the cases were ≥65 years, and 46% were confirmed to have occurred at home. The BCPR rate showed significant improvement from 50.2% in 2013 to 61.5% in 2015 (*P* < 0.05).

Neighbourhood characteristics

A total of 2050 PCDs were included in the analysis. There were no OHCA in 40 PCDs, and we could not include PCD 'TW6' which refers to Heathrow Airport, for which neighbourhood characteristics are not available (56 cases).

Out-of-hospital cardiac arrest incidence

There was significant variation in the OHCA incidence by a number of neighbourhood characteristics ([Supplementary material online, Table S1](#)). In summary, the percentage of all OHCA in the registry increased with increasing level of deprivation, population density, degree of urbanization, proportion of population of mixed and non-white ethnicity, proportion in higher occupations or never worked, proportion born outside UK, and proportion aged >65 years. Out-of-hospital cardiac arrest incidence in each PCD varied considerably, averaging at 135.7/100 000 resident population (median 127.6; range 16.7–2649.0) (Table 1) Incidence was also calculated on the basis of workday population, and this averaged at 131.2/100 000 (median 130.0; range 2.03–768.0). This is the incidence for the whole study period (not the annual incidence) and was used to identify high-risk PCDs, it should not be used to compare with other population-based studies.

Figure 1 shows the variation in OHCA incidence in England by PCD. The map indicates high OHCA incidence (>500/100 000) in areas of Westminster, Birmingham, Wolverhampton, East London, along the South-East and North-East coasts, and the Lake District. There are slight differences in the pattern between the two maps because some PCDs have a significantly higher, or lower, workday population that would influence the incidence. For example, the City of London PCD 'EC' has an average residential population of 2767 but an average workday population of 27 919; the corresponding OHCA incidences are similarly different 590.3 and 30.3, respectively.

The characteristics of the PCDs with high OHCA incidence (i.e. >median) are given in Table 2. Mean residential population density was significantly higher in PCDs with a high OHCA incidence, whether the latter was calculated on the basis of residential population or workday population. In contrast, the mean workday population density was significantly lower in these PCDs. Postcode districts with a greater than median OHCA incidence based on residential population (>127.6/100 000) or workday population (>130.0/100 000) were more urbanized (lower rural/urban index), had fewer people in managerial occupations and with educational qualifications, and fewer people with a white ethnic background. These PCDs also had more people in routine/manual occupations and with mixed/non-white ethnic background. There was also a greater degree of deprivation in these areas (lower IMD and higher household deprivation).

In contrast, high residential incidence PCDs had a lower proportion of people in intermediate occupations, people born in the UK

Table 1 Characteristics of out-of-hospital cardiac arrests included in the analysis

	Year of incident			
	2013 ^a	2014	2015	Total
All EMS attended OHCA's				
Number	15 639	24 496	27 084	67 219
Age (years):				
Mean (SD)	68.3 (19.4)	67.6 (20.5)	67.7 (19.9)	67.8 (20.0)
Median	73.0	72.0	72.0	65.0 (27.6)
Sex, male (%)	63.0	57.6	61.6	60.5
PCD ^b Incidence (/100 000)				
Mean (SD)				135.7 (127.4)
Median				127.6
Range				16.7–2649.0
Bystander Witnessed OHCA's				
Number	6983	9386	12 145	28 514
Proportion of total cases (%)	44.7	38.3	44.8	42.4
Age (years):				
Mean (SD)	69.8 (17.7)	69.7 (17.9)	69.1 (18.5)	69.5 (18.1)
Median	73.0	73.0	73.0	73.0
Sex, male (%)	64.9	61.9	63.4	63.3
≥65 years (%)	65.4	65.8	65.5	65.6
Home (%)	39.0	44.6	50.5	45.7
Presenting shockable rhythm (%)	27.7	30.0	27.4	28.3
Initial cardiac aetiology (%)	80.3	79.6	81.4	80.5
Bystander CPR (%)	50.2	59.9	61.5	58.2
PCD BCPR ^c rate (%)				
Mean (SD)				56.8 (26.0)
Median				60.0
Range				0–100

^a9-months data only.^bPostcode district.^cBystander CPR.

and aged 65 years and over, and an increased proportion of people born outside the UK. The opposite pattern was observed for high workday incidence PCDs for these variables.

Bystander cardiopulmonary resuscitation

Briefly, BCPR rates increased with decreasing levels of deprivation and population density; and increasing proportion of population of white ethnicity, proportion of people in higher and intermediate occupations, proportion aged <65 years, and proportion born in the rest of the EU ([Supplementary material online, Table S1](#)).

Figure 2 shows the variation in BCPR rates in bystander-witnessed OHCA's in English PCDs. Low BCPR rates were observed in the North-East and Yorkshire, in parts of Milton Keynes, Cornwall, Somerset, Derbyshire, Wiltshire, Kent, and Leicester.

Postcode district BCPR rates ranged from 0% to 100% with a mean of 56.8% [standard deviation (SD) 26.0%]. Ignoring those PCDs in which BCPR rate was 0 or 100 ($n = 333$) had no effect on the mean (56.8%, SD 18.2%; range 4.8–94.4%). Table 2 gives the characteristics of PCDs where the BCPR rate was less than or greater than 60%.

The average workday population density in PCDs with a high BCPR rate was significantly higher than in PCDs with a low BCPR rate, although categorized density showed no difference between the two. Residential population density, on the other hand, was lower, 20.6/ha compared to 21.3/ha. The rural/urban index was significantly higher in PCDs with a low BCPR rate, indicating a greater level of rurality. Postcode districts with high BCPR rate had significantly more people in managerial and professional occupations, and significantly fewer in intermediate, routine, and manual occupations compared to PCDs with low BCPR rates. These PCDs had significantly more people of white ethnic background, and significantly fewer of mixed or non-white ethnicity. Deprivation (lower IMD) was significantly greater in low-BCPR PCDs. There was no difference between the two groups in where people were born or the age composition.

High-risk postcode districts

High-risk PCDs were defined as those where the OHCA incidence was greater and the BCPR rate was below their respective medians (residential incidence: 127.6/100 000; workday incidence: 130.0/100 000; BCPR rate 60%). A total of 490 (23.9%) PCDs were judged

to be residential and 498 (24.3%) workday high-risk (Table 3), and their location is shown in Figure 3. In all, 73 (14.9%) PCDs categorized as high-risk based on residential population incidence were not categorized as high-risk based on workday population incidence, whereas 81 (16.3%) that were not categorized as high-risk based on residential population incidence were categorized as high-risk based on workday population incidence. Very few are in the South-West or South-Central regions, but a large number are concentrated in the North-East, Yorkshire and in and around Birmingham. There are also pockets in and around London and on the South-East coast. Generally, in high-risk PCDs, irrespective of whether the incidence was based on the resident population or the workday population, there was a greater degree of urbanization (lower rural/urban index), a greater proportion of people in routine occupations, of mixed/non-white background, and people whose activities were limited. There were fewer people in managerial and intermediate occupations, of white ethnic background and with educational qualifications. These areas were also more deprived (lower IMD and higher household deprivation). Country of birth did not appear to have a significant role.

Regression analysis

Bivariate logistic regression analysis of PCD risk (high or low) indicated significant associations with all the neighbourhood characteristics (Supplementary material online, Tables S3 and S4). Backward stepwise regression of significant variables resulted in the final model in Table 4. The odds of a PCD being high-risk based on residential

population incidence increased significantly with the proportion of people aged over 65 years and where the proportion of people had no educational qualification, and decreased with increasing population density category and degree of rurality, and with the IMD. When high-risk was defined using OHCA incidence based on workday population, the odds increased with residential population density and proportion of people in managerial occupations. However, the odds ratio (OR) decreased with workday population density, the proportion of people with educational qualifications and where their long-term health did not restrict activities, and also with increasing rurality. Both models showed good calibration (HL-Test $P > 0.1$) and AUC was fair (0.7).

Discussion

We have identified a number of high-risk PCDs in England where there was a high incidence of out-of-hospital cardiac arrest and a low rate of BCPR in bystander-witnessed OHCA. These areas were characterized by a greater residential population density and lower workday population density; increased urbanization; a greater proportion of people working in intermediate and routine occupations, and lower proportion in managerial occupations; greater proportion of mixed and non-white ethnic groups, and lower percentage of white ethnicity; lower proportion with high educational qualifications; and a greater level of deprivation (lower IMD). Postcode districts

Table 2 Demographic characteristics of postcode districts with high and low out-of-hospital cardiac arrest/bystander cardiopulmonary resuscitation incidence (mean and standard deviation)

	All OHCA	Residential OHCA incidence		Workday OHCA incidence		BCPR rate	
		High (>127.6/100 000) (n = 1021)	Low (≤127.6/100 000) (n = 1029)	High (>130/100 000) (n = 1022)	Low (≤130/100 000) (n = 1028)	High (≥60%) (n = 1041)	Low (<60%) (n = 1009)
Resident population density:							
Continuous (/ha)	20.9 (28.6)	24.9 (30.8)**	17.0 (25.7)	22.5 (28.8)*	19.3 (28.4)	20.6 (29.4)	21.3 (27.8)
Category	2.52 (0.92)	2.66 (0.93)**	2.40 (0.89)	2.58 (0.91)**	2.47 (0.93)	2.56 (0.88)	2.49 (0.95)
Workday population density:							
Continuous (/ha)	35.9 (116.2)	50.6 (151.3)**	21.2 (61.3)	20.6 (31.2)**	51.0 (159.7)	41.4 (140.3)*	30.2 (84.1)
Category	2.53 (0.99)	2.68 (1.03)**	2.37 (0.92)	2.50 (0.88)	2.55 (1.09)	2.49 (1.04)	2.56 (0.94)
Rural/urban index	3.4 (2.1)	3.0 (2.0)**	3.8 (2.0)	3.2 (2.0)**	3.7 (2.0)	3.5 (2.2)*	3.3 (2.0)
Long-term health, activities limited (%)	17.7 (4.1)	18.3 (4.4)**	17.0 (3.6)	18.6 (3.9)**	16.8 (4.0)	17.5 (4.2)*	17.9 (3.9)
Occupation (%):							
Higher	32.6 (9.7)	31.1 (10.3)**	34.2 (8.8)	31.2 (9.1)**	34.0 (10.1)	33.8 (9.8)**	31.4 (9.5)
Intermediate	22.9 (4.5)	22.6 (4.7)**	23.3 (4.3)	23.5 (3.9)**	22.4 (5.0)	23.4 (4.6)**	22.5 (4.3)
Routine	31.0 (9.4)	32.0 (10.2)**	30.0 (8.5)	32.5 (9.1)**	29.5 (9.5)	29.8 (9.4)**	32.2 (9.4)
Ethnic background (%):							
White	88.4 (15.9)	85.6 (18.4)**	91.1 (12.4)	87.6 (17.1)*	89.1 (14.5)	89.0 (15.1)	87.7 (16.6)
Mixed	2.8 (3.7)	3.4 (4.4)**	2.2 (2.6)	3.0 (4.1)*	2.6 (3.2)	2.7 (3.4)	2.9 (4.0)
Non-white	8.8 (12.6)	11.0 (14.4)**	6.7 (10.0)	9.3 (13.4)	8.3 (11.7)	8.2 (12.0)*	9.4 (13.1)
Educational qualifications, yes (%)	59.6 (9.1)	57.3 (9.7)**	61.9 (8.0)	57.2 (8.5)**	62.0 (9.2)	60.6 (8.9)**	58.6 (9.3)
Country of birth (%):							
UK	87.7 (12.8)	85.8 (14.8)**	89.6 (10.0)	88.3 (12.4)*	87.1 (13.1)	87.4 (13.3)	88.0 (12.2)
EU	4.1 (3.8)	4.5 (4.4)**	3.7 (3.1)	3.8 (3.5)**	4.4 (4.1)	4.3 (4.1)	3.9 (3.5)
Other	8.1 (9.6)	9.6 (11.2)**	6.7 (7.4)	7.9 (9.6)	8.4 (9.5)	8.2 (9.8)	8.1 (9.4)
IMD	3.0 (1.0)	2.8 (1.0)**	3.3 (1.0)	2.9 (1.0)**	3.2 (1.1)	3.1 (1.1)*	3.0 (1.0)
Household deprivation (%)	56.4 (8.7)	59.0 (8.8)**	53.8 (7.8)	57.9 (8.5)**	54.9 (8.8)	55.7 (8.6)**	57.1 (8.8)
Age over 65-years (%)	17.5 (5.7)	17.3 (5.9)	17.7 (5.4)	18.0 (5.4)**	17.1 (6.0)	17.8 (6.0)*	17.2 (5.4)

* <0.05 ; ** <0.01 .

were in various parts of the country including the North-East, Midlands, East of England, London, and South-East. This is the first such study in England, and the only one known that has examined the picture on a national basis.

Previous studies have observed an increase in population density to be associated with an increased OHCA incidence and a decreased likelihood of BCPR.^{14–18} In multivariate regression analyses, population density was observed to be the primary non-clinical driver for disparity in BCPR provision.^{16,17} Related to population density, the degree of urbanization/rurality has also been shown to impact on BCPR.^{19,20}

The reasons why BCPR rates are higher in rural, less densely populated areas can be partly explained by lower deprivation in these areas. It has also been suggested that residents of these areas may think that because it would take the EMS time to arrive they should act urgently.¹⁷ There is also less social anonymity in small towns and other less densely populated areas, and the presence of factors that generate greater personal and social motivators to perform BCPR that are less likely in urban areas. For example, a survey in Arizona

observed that over 80% of people would be willing to perform CPR on a family member compared to only 50% on a stranger.²¹ Conversely, in more populated areas, bystanders may perceive help will arrive soon and consequently feel their action will add little benefit. There is also the so-called 'bystander effect' where individuals are less likely to offer help to a victim when other people are present, because of ambiguity, a lack of cohesiveness, and diffusion of responsibility.²²

Although BCPR rates are higher in less densely populated areas, the outcomes are still poor, probably because of the increased EMS arrival time and subsequent delay in initiating advanced life support. However, in these areas survival is still higher if a patient does receive BCPR than when they do not, and is even better if an automatic external defibrillator is also used by a bystander.¹⁸

Previous studies have shown that large numbers of OHCA occur in areas with a large population density, in Denmark,²³ Japan,¹⁸ USA,⁶ and Australia.²⁴ Folke et al.²³ observed population density had the strongest association with OHCA occurrence, rate ratio for OHCA doubling with every quartile of population density. Nehme et al.²⁴

Figure 2 Variation of bystander cardiopulmonary resuscitation rate in bystander witnessed out-of-hospital cardiac arrests in English postcode districts.

observed between 2003 and 2011, that as population density increased, age-adjusted incidence increased concomitantly, for both EMS attended and EMS treated OHCA. We demonstrated in PCDs with a high residential OHCA incidence, the residential population density was about 50% higher compared to PCDs with a low incidence. In contrast, Straney *et al.*¹⁶ noted in Local Government Areas (LGA) of Victoria, Australia between 2011 and 2013 with the highest incidence the population density was significantly lower than in areas with the lowest incidence. Stromsoe *et al.*¹⁴ also noted in Sweden the incidence was lower in areas with the highest population density but the association disappeared when incidence was adjusted for age and gender.

Studies have also shown that OHCA incidence is also increased in areas with significant population movement (e.g. railway stations, airports, and shopping centres) explaining the heterogeneity of incidence between areas,²⁵ and that this factor was a main driver in identifying 'hot spots' for OHCA.^{25,26} We could not identify specific locations with a high population movement but were able to look at workday population which gives an idea of commuting patterns and

areas that attract employees. We observed that in PCDs with a high OHCA incidence the workday population density was 2.4 times greater than in PCDs with a low incidence, suggesting a significant influx of workers into these PCDs. Heathrow Airport, which has its own unique postcode, but could not be included in the overall analysis because we could not obtain neighbourhood characteristics for it, has a very large population movement and had a high number of OHCA (67), and also a high BCPR rate (87%). The benefit of receiving BCPR, and defibrillation from an AED, in these areas has been highlighted in the UK, where the chances of achieving ROSC were almost doubled and survival to discharge trebled.²⁷

Although there was no difference in residential population density between PCDs with a high BCPR rate compared to low BCPR rate, the workday population density was significantly higher (about 40%) in the former. Previous studies have consistently shown an inverse relationship between BCPR rate and population density,^{14,18,24} and Straney *et al.*¹⁶ observed that population density explained 73% of the variation of receiving BCPR among LGAs.

Table 3 Demographic characteristics (mean and standard deviation) of postcode districts defined as high/low risk

	Residential population ^a		Workplace population ^b	
	High-risk (n = 490)	Low risk (n = 1560)	High-risk (n = 498)	Low risk (n = 1560)
Resident population density:				
Continuous (/ha)	25.7 (30.3)**	19.4 (27.9)	23.6 (28.8)*	20.1 (28.5)
Category	2.69 (0.89)**	2.47 (0.92)	2.63 (0.88)**	2.49 (0.93)
Workday population density:				
Continuous (/ha)	40.6 (104.2)	34.4 (119.7)	21.0 (24.8)**	40.7 (132.4)
Category	2.72 (0.97)**	2.47 (0.99)	2.56 (0.86)	2.52 (1.03)
Rural/urban index	2.9 (1.8)**	3.6 (2.1)	3.0 (1.9)**	3.6 (2.1)
Long-term health, activities limited (%)	18.9 (4.2)**	17.3 (4.0)	19.0 (3.9)**	17.3 (4.0)
Occupation (%):				
Higher	29.2 (9.7)**	33.7 (9.5)	30.0 (9.0)**	33.5 (9.8)
Intermediate	22.0 (4.4)**	23.2 (4.5)	22.8 (3.8)	23.0 (4.7)
Routine	33.8 (10.0)**	30.1 (9.1)	34.0 (9.2)**	30.1 (9.3)
Ethnic background (%):				
White	85.2 (19.2)**	89.4 (14.5)	87.5 (17.4)	88.7 (15.4)
Mixed	3.5 (4.9)**	2.6 (3.2)	3.1 (4.3)*	2.7 (3.4)
Non-white	11.3 (14.9)**	8.0 (11.7)	9.4 (13.5)	8.6 (12.3)
Educational qualifications, yes (%)	55.8 (9.7)**	60.8 (8.6)	56.1 (8.6)**	60.7 (9.0)
Country of birth (%):				
UK	86.5 (14.0)*	88.1 (12.4)	88.6 (12.3)	87.4 (12.9)
EU	4.2 (4.0)	4.0 (3.7)	3.7 (3.4)*	4.2 (3.9)
Other	9.2 (10.8)**	7.8 (9.2)	7.7 (9.5)	8.3 (9.6)
IMD	2.6 (1.0)**	3.2 (1.0)	2.8 (1.0)**	3.1 (1.1)
Household deprivation (%)	60.3 (8.7)**	55.2 (8.4)	59.0 (8.3)**	55.6 (8.7)
Age over 65-years (%)	17.2 (5.7)	17.6 (5.7)	17.8 (5.3)	17.4 (5.8)

^aHigh risk defined as OHCA incidence >127.6/100 000 and BCPR rate <60%.

^bHigh risk defined as OHCA incidence >130.0/100 000 and BCPR rate <60%.

*<0.05; **<0.01.

Although some areas with a high population density and or workday population density had a high OHCA incidence they were not considered 'high risk', because they also had a high BCPR rate. An increased population density is not only predictive of OHCA incidence and BCPR rate, it is also significantly associated with the proportion of OHCA of cardiac aetiology,¹⁸ cases with an initial rhythm of VF/VT,²⁴ decreased ambulance response time,^{14,18} and improved outcomes (transport with ROSC and survival to discharge).^{14,24}

High-risk PCDs based on residential population, tended to have a greater population density (residential and workday) than low risk PCDs. Previously, Fosbol et al.⁶ observed an odds of a census tract having a high rate of cardiac arrest and low rate of BCPR decreased with increasing population density, although this was not significant.

The degree of rurality, like population density, has a significant association with OHCA incidence and likelihood of BCPR. We observed PCDs with a low OHCA incidence and a high BCPR rate were more rural. Similarly, Uber et al.¹⁷ observed OHCA clustering in more urban areas, but subjects with an OHCA in an urban area was less likely to receive BCPR. In Ireland, Masterson et al.²⁸ observed a similar relationship, and also that more cases had defibrillation attempted before EMS arrival. However, they noted that these patients were less likely to arrive at hospital with a ROSC and to be discharged from hospital alive.

We showed that where there were larger proportions of people who indicated they were of mixed race or non-white ethnic background, a lower percentage from a white background, the PCDs were more likely to be high-risk. The ethnic make-up of a community has been widely recognized to impact on whether an OHCA in that community will receive BCPR or not. Many studies, mostly in the USA, have observed neighbourhoods that are largely made up of Black, Hispanics, or Latinos have significantly lower BCPR rates, compared to mainly white neighbourhoods.^{3,5,17,29–31} In a similar study to ours, 'hot spot' census tracts in Ohio had a significantly higher proportion of African-Americans than 'cold spot' tracts,⁸ although census tracts cover a smaller population range (4000–7000) compared to English PCDs (136–154 233). A previous study in London observed that BCPR rates were significantly lower among South Asian OHCA patients compared to white OHCA patients.³² A recent meta-analysis concluded that the odds that a Black patient would receive BCPR was significantly reduced [OR 0.63, 95% confidence interval (95% CI) 0.53–0.76] compared to their white counterparts,³³ and also less likely to survive to hospital admission and discharge. Akin to this a link between low BCPR rates and tracts with large numbers of people with limited English proficiency has also been observed.^{34,35} The exact reasons are unknown but could

Figure 3 Location of high-risk postcode districts with low bystander cardiopulmonary resuscitation rate (<60%) and: (A) high out-of-hospital cardiac arrest residential incidence (>127.6/100 000); (B) high out-of-hospital cardiac arrest workday incidence (>130.0/100 000).

Table 4 Multivariate logistic regression analysis of high-risk postcode districts on neighbourhood characteristics final model

Variable	Residential high-risk			Workday high-risk		
	OR	P> z	95% CI	OR	P> z	95% CI
Residential population density:						
Continuous (/ha)	1.01	0.04	1.00–1.01	1.06	0.00	1.04–1.08
Category	0.75	0.05	0.57–1.00			
Workplace population density (/ha)				0.94	0.00	0.92–0.96
Rural/urban index	0.84	0.00	0.76–0.92	0.89	0.00	0.83–0.95
Long-term health, activities not limited (%)				0.93	0.00	0.89–0.96
Occupation (%):						
Higher				1.06	0.00	1.02–1.09
Intermediate	0.93	0.00	0.89–0.96			
Routine	0.97	0.01	0.94–0.99			
Educational qualifications, yes (%)	0.92	0.00	0.89–0.94	0.92	0.00	0.88–0.95
Proportion of population aged ≥65 years (%)	1.07	0.00	1.04–1.10			

Hosmer–Lemeshow $\chi^2 = 2018$ ($P = 0.642$); AUC = 0.70.

Hosmer–Lemeshow $\chi^2 = 1982$ ($P = 0.830$); AUC = 0.72.

be cultural or related to deprivation, as the US studies have shown that the most deprived areas tend to have a large ethnic minority population.

Neighbourhoods with a low socioeconomic status (measured by various indices including household income, level of poverty, etc.) and high levels of deprivation are known to have a high OHCA

incidence and low BCPR rate.^{5–8,36–42} We observed that high-risk areas were more likely to have fewer people in managerial and intermediate occupations and more in routine occupation, and were more deprived. There is consensus that OHCA incidence is significantly higher in deprived neighbourhoods compared to least deprived. Individuals in the most deprived areas of UK have been shown to have a reduced life expectancy and also spend a smaller proportion of their shorter lives in good health.⁴³ However, the opposite trend is seen with regards to the likelihood of receiving BCPR. In a previous study in North-East England BCPR incidence was observed to increase from 14.5% in the most deprived neighbourhoods to 23.3% in the least deprived,⁴⁴ and the odds of receiving BCPR in the latter was 1.78 (95% CI 1.32–2.39) compared to former. In our analysis of the data for the whole country the odds, whilst a little lower had narrower CIs (OR 1.14, 95% CI 1.05–1.23). The reasons why deprived areas are at high-risk are not clear but could be due to access to training, as it has been shown that people in UK in higher social grades, and full-time employment, are more likely to have received training in CPR (and AED use), and probably as a consequence show a greater willingness to perform CPR (C. Hawkes et al. submitted for publication). It could also be due to the stigma and fears around initiating BCPR.⁴⁵

Socioeconomic status is not only important predicting OHCA incidence and likelihood a case receives BCPR, it is also important for survival, in cases that have received BCPR the likelihood of survival increases with an increase in socioeconomic status.^{46,47}

Limitations

A limitation of the study was that we were not able to geocode approximately 12% of the OHCA which may have biased the results. The majority of these were located in the South-West (81%). The main reason was that only the Utstein location could be provided and is why the OHCA incidence is low in that region (Figure 1). We excluded these 12% because it is well known that witnessed arrests are strongly associated with BCPR,⁴² and rates of witnessed arrests fluctuate between the regions and over time.

We used PCD as the proxy for neighbourhood and assumed that its characteristics reflect the common characteristics shared by most of the individuals with OHCA there and the bystanders living in or moving through there. High-risk areas can change over time, therefore it is important to consider the fact in the development and testing of community-based interventions targeting these regions.⁴⁸ We assigned each OHCA to the PCD in which it occurred, this means that in PCDs where people commute to work or visit for holidays, or cities or town centres, may overestimate the incidence for that PCD. This was the case for a number of locations, where we also noted that BCPR rates were low and could be a focus for training and/or publicity. We could have used lower or medium super output areas as the proxy for neighbourhood, but this would have reduced the number of OHCA in each significantly that may have biased the results.

We did not separate OHCA events by public or private events, and it is possible that certain PCDs are high-risk because they have larger daytime populations.³¹ However, a number of the high-risk PCDs were in residential areas, where it is known that the majority of OHCA occur; an analysis of 2014 data from the OHCAO registry indicated that about 61% of known OHCA occurred in the home,¹

other studies have indicated about 80%. We were only able to confirm the location where a limited number of OHCA occurred according to the Utstein criteria, e.g. home, public place, etc., the number confirmed as occurring in the home was below that observed elsewhere.

The categories chosen for the various neighbourhood characteristics were arbitrary and may not be generalizable across the country or in cross-nation comparisons. In addition, in the assessment of deprivation within a PCD we used the IMD which has been developed for use in the UK. If in the future we wish to compare between countries within the UK, adjustments will have to be made because of the slightly different ways the IMD is calculated in each country.⁴⁹

Lastly, there may be other confounding factors that we did not consider that could impact on whether an individual receives BCPR or not, including the variation in neighbourhood cohesiveness or collective efficiency.⁵ We also did not look at EMS variables here, some of which are known to impact on whether an individual is likely to receive BCPR or not. These include: arrest location, age and sex of patient, their ethnicity, and time/day at which event occurred.

Conclusions

The study provides a key insight into the variation in OHCA incidence and BCPR rate across England. We have been able to identify the neighbourhood characteristics of high-risk areas that experience a high OHCA incidence and low BCPR rate that could be targeted for programmes of training in CPR, and AED use. These high-risk areas could also be targets for public access defibrillator (PAD) placement strategies; however, further research is required and ongoing to identify the optimal location for PADs.

Supplementary material

Supplementary material is available at *European Heart Journal – Quality of Care and Clinical Outcomes* online.

Collaborators

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